

Economic impacts of climate change on agrifood markets: A bio-economic approach with a focus on the EU

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Abstract:

Projections for world food production and prices play a crucial role to evaluate and tackle future food security challenges. Understanding how these projections will be affected by climate change is the main objective of this study. By means of a bio-economic approach we assess the economic impacts of climate change on agrifood markets, providing both a global analysis and a regionalised evaluation within the EU. To account for uncertainty, we analyse the IPCC emission scenario A1B for the 2030 horizon under several simulation scenarios that differ in (1) the climate projection, from HadleyCM3 (warm) or ECHAM5 (mild) global circulation models; and (2) the influence of CO₂ effects. Results of this study indicate that agrifood market projections to 2030 are very sensitive to climate change uncertainties and, in particular to the magnitude of the carbon fertilization effect.

Keywords: climate change, agrifood markets, bio-economic modelling, food prices

1. Introduction

There is a growing body of evidence on the effects of climate change on agriculture (Parry et al. 2004, Nelson et al. 2009). Many studies have analysed the effects of climate change on crop yields, showing that the magnitude and the direction of these effects will differ across regions, depending both on natural and anthropogenic conditions (Parry et al. 2004, Tubiello and Fischer 2006). Other studies put the accent on the high level of uncertainty when analysing the potential response of crops to climate change, due to multiple greenhouse emission pathways, climate models and crop impact models (Müller et al. 2010, Rosenzweig et al. 2013).

Assessing the impacts of climate change on agriculture requires not only the identification of regional yield changes but also the analysis of induced impacts on global crop production and prices. Efforts to anticipate how climate change will affect future food production and prices include the seminal works of Tobey et al. (1992) and Reilly and Hohmann (1994). Using an agricultural partial equilibrium model, these authors showed that negative (positive) yield changes would be balanced by interregional adjustments in production and consumption and corresponding trade flows. Recent global assessments of climate change impacts confirm these early findings that market effects are a significant adjustment mechanism to the impacts of climate change on agriculture (Nelson et al. 2010, Hertel et al. 2010, Lobell et al. 2011, Nelson et al. 2013).

Focusing on EU agriculture, most of the studies focus on biophysical effects, indicating that, while in northern Europe climate change may produce positive effects on average crop yields, in southern Europe negative effects are likely to predominate (Wolf and Van Diepen 1995, Donatelli et al. 2012). Studies analysing the economic impacts of climate change are restricted to selected regions or do not take into account feedback effects through world market prices and interregional trade (Ciscar et al. 2011, Möller et al. 2011, Shrestha et al. 2013).

In this paper, we simulate the economic impacts of climate change on agricultural markets under consideration of uncertainties in global climate projections. Climate impacts are analysed at the regional level within the EU, whilst the feedback effects from world

agrifood markets are accounted for. The innovative aspect of this study is that it investigates the combination of biophysical and economic impacts of climate change both globally and at subnational level within the EU, while taking into account the uncertainty with respect to the CO₂ fertilization effects.

2. Methodology

2.1. Bio-economic modelling approach

In order to assess the economic impacts of climate change on agriculture, we link the biophysical model WOFOST (capable to simulate yield effects under alternative climate scenarios) to the agro-economic model CAPRI (capable to anticipate global and EU-wide impacts on agrifood markets). As long-term macroeconomic and agricultural projections are highly uncertain, we refrain from using a very long projection period and, consequently, the time horizon chosen for this study is 2030.

Future crop yield developments are subject to considerable uncertainty, particularly with regard to climate projections, the magnitude of the carbon fertilization effect and likely changes in management practices. To account for such uncertainties, several simulation scenarios have been defined, all of them based upon the IPCC emission scenario A1B (i.e, rapid economic growth, convergence across regions and balanced emphasis across all energy sources), which is one of the most widely studied scenarios (IPCC 2007).

As regards climate projections, we took results from two GCMs (ECHAM5, 'mild' projection, and HadleyCM3, 'warm' projection), both bias corrected and downscaled from the original ENSEMBLE data set by the same regional climate model to a 25 km grid resolution. A more detailed comparison of the weather data generated by the two models is available in Donatelli et al. (2012).

The magnitude of carbon fertilization effects has also been evaluated. Therefore, the simulation scenarios can be summarized as follows:

- Echam-CO₂: A1b emission scenario, ECHAM5 climate projection, full CO₂ fertilization.
- Hadley-CO₂: A1b emission scenario, HadleyCM3 climate projection, full CO₂ fertilization.
- Echam-noCO₂: A1b emission scenario, ECHAM5 climate projection, no CO₂ fertilization.
- Hadley-noCO₂: A1b emission scenario, HadleyCM3 climate projection, no CO₂ fertilization.

2.2. Modelling yield effects of climate change

To simulate impacts of climate change on crop yields, we used the WOFOST (World Food Studies) model developed by Wageningen University (Van Diepen et al. 1989, Boogaard et al. 1998). WOFOST works on a daily basis, relying in the simulation of interactions between crop production and ecological factors, simulating both potential yield and water-limited yields. For this study, WOFOST was run through the BioMA (Biophysical Model Application) platform that provides a framework to easily run simulations under different assumptions and compare their results. The standard WOFOST was modified to better model the impact of changes in CO₂ atmospheric concentration.

WOFOST simulated the yield effects of climate change and carbon fertilization on crop yields at 25km grid resolution all over the EU. The crops covered by this study were wheat, maize, barley, rye, field beans, rapeseed, sunflower, sugar beet and potato. For each of these

nine crops, simulations were performed under rainfed and fully irrigated conditions, assuming no change in farming practices or technical progress. The results of the simulations were aggregated at regional level (NUTS2) using regional statistics on crop areas.

For non-EU regions, climate induced changes on crop yields were based on the work done for the 2010 World Development Report (Müller et al. 2010). Crop yield changes are simulated for the period 2000-2050 using the LPJmL model (Bondeau et al. 2007) for several climate change scenarios, including those analysed in this paper (A1B implemented by GCMs HadleyCM3 and ECHAM5). Simulations are also performed both with and without effects of CO₂ fertilization.

2.3. Modelling economic effects of climate change on agricultural markets

To assess the effects of climate induced yield changes on agricultural production and prices, both at global and EU-wide level, the global agro-economic CAPRI (Common Agricultural Policy Regionalised Impact) model has been used.

CAPRI is a tool for ex-ante impact assessment of agricultural, environmental and trade policies with a focus on the European Union. It is a global spatial, partial equilibrium model, solved by sequential iteration between supply and market modules (Britz and Witzke 2012).

The supply module consists of independent regional agricultural nonlinear programming models for EU28 and candidate countries. Supply models depict farming decisions in detail at subnational level (NUTS-2 level or farm type level). The mathematical programming approach offers a high degree of flexibility in capturing important interactions between production activities, the environment and the effects of Common Agricultural Policy (CAP) and related policy measures. The market module is a static partial equilibrium model with global coverage, depicting about 60 commodities (primary and secondary agricultural products) and 40 trade blocks. It allows for simulating bilateral trade flows and related bilateral, as well as multilateral, trade instruments.

The equilibrium in CAPRI is obtained by letting the supply and market modules iterate with each other. The unique combination of regional supply-side models with a global market model for agricultural products provides simulated results for the EU at sub-member state level, whilst at the same time models global agricultural markets. CAPRI has been used in numerous assessments of agricultural, trade and environmental policies (Burrell et al. 2014, Gocht et al. 2013, Leip et al. 2011, Burrell et al. 2011, Blanco et al. 2010).

The comparative-static structure of CAPRI makes this model mainly suited for counterfactual analysis against an existing baseline or reference scenario. The CAPRI baseline depicts the projected agricultural situation in the simulation year under exogenous assumptions and a status-quo policy setting. The baseline used in this study builds upon the medium-term outlook for EU agricultural markets and income for 2020 (European Commission 2012). Furthermore, it captures developments in exogenous variables, such as the path of technological change, population growth, GDP growth and agricultural market developments for the horizon year 2030.

The baseline scenario defines the reference situation and thus serves as a comparison point for the simulation scenarios that were defined in the previous section. For each simulation scenario, biophysical simulations provide climate induced crop yield changes, which are incorporated in CAPRI as exogenous productivity shifters. For EU regions, changes in crop yields are explicitly incorporated in the regional programming models defined at the

NUTS-2 level (supply module). For non-EU regions, changes in crop yields are incorporated in the supply functions that are defined for each trade block (market module).

3. Results and discussion

3.1. Biophysical simulation results

WOFOST simulations performed at 25km grid resolution provide changes in both potential and water-limited yields for nine of the most widely grown crops in the EU.

Looking first at potential yield changes, simulation results suggest that at EU level potential yields will increase under full carbon fertilization but will decrease in the scenario without CO₂ fertilization effects (Figure 1). As there is considerable uncertainty on the magnitude of this CO₂ fertilization effect, full CO₂ and no-CO₂ scenarios represent opposite ends of the spectrum.

For most of the crops, the Hadley realization (warm) gives more pessimistic figures than the Echam (mild) realization.

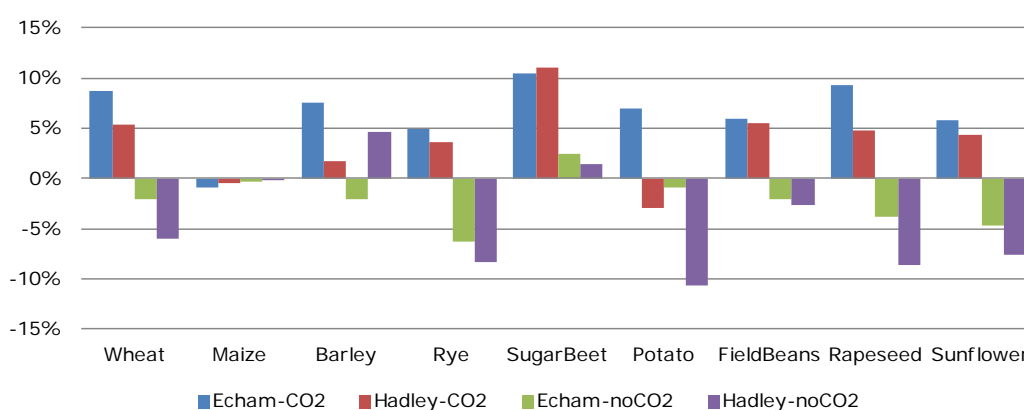


Figure 1. Percentage change in potential yields (EU average)

Under water-limited conditions, the average EU crop yields decrease under both Echam and Hadley realizations (Figure 2). Maize seems to be the most affected crop, probably due to the fact that it does not benefit a better CO₂ assimilation rate due to higher CO₂ concentration. Wheat, barley and rapeseed will potentially be less affected.

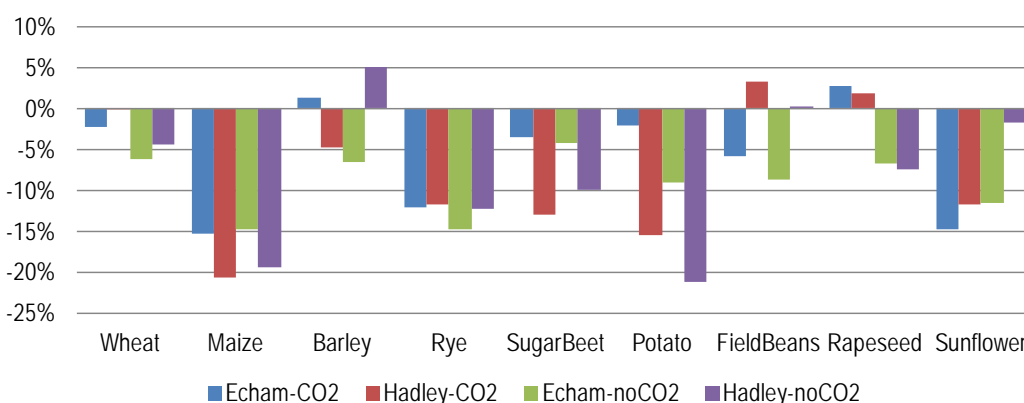


Figure 2. Percentage change in water limited yields (EU average)

Aggregate results at the EU level hide significant disparities observed at regional levels. Figure 3 shows regional variations of climate change impacts on potential maize yields.

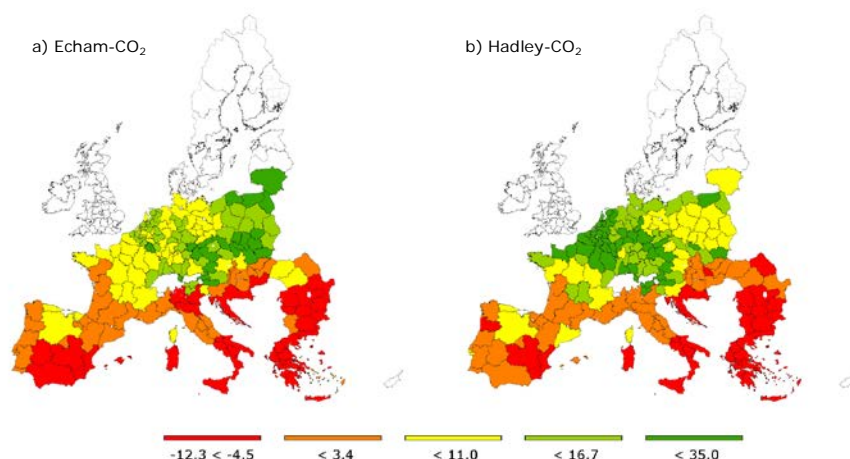


Figure 3. Percentage change in potential yield (maize)

For those crops not explicitly modelled by WOFOST, climate induced yield changes are assumed to be similar to changes for an analogous crop or crop group. Since CAPRI works with actual crop yields, for each simulation scenario actual yield changes were approximated by applying irrigation shares (also available at NUTS-2 level).

For non-EU regions, climate induced changes on actual crop yields were based on previous studies (Müller et al. 2010). At the global level, crop yields are expected to increase in scenarios with carbon fertilization, while crop yield decreases are projected in scenarios without CO₂ effects. The highest yield increases are found in Asian countries and the Former Soviet Union. In contrast, the highest yield decreases are found in North America, Latin America, Middle East and African countries.

3.2. Climate induced effects on agricultural production and prices

Increase in exogenous crop yields, and thus productivity, would be counterbalanced by decrease in crop prices and vice versa, leading to interregional adjustments in production, consumption and trade. Figure 4 summarizes climate effects on global agricultural production.

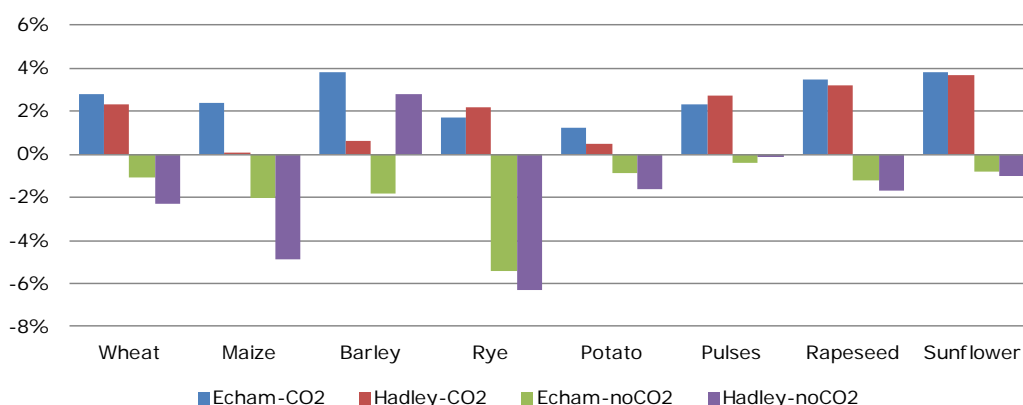


Figure 4. Effects on global production (% change from baseline)

Under full carbon fertilization, exogenous yield effects are positive at the global level. Not surprisingly, global production is expected to (moderately) increase in these scenarios. Without CO₂ effects, in contrast, global production is expected to decrease, with the exception of barley in the Hadley realization. Hence, the carbon fertilization effect appears as one of the key factors influencing the direction of effects. While the influence of CO₂ fertilization is generally acknowledged, and hence the scenarios without CO₂ are unlikely, there is considerable uncertainty on the level of this CO₂ effect (Easterling et al. 2007, Tubiello et al. 2007) and, therefore, on the market effects of climate change.

Focusing at scenarios with CO₂ effects, global production increases in the range of 0.1-3.8% result in global price decreases in the range of 1-16% (see figure 5). Furthermore, stronger production increases in the Echam realization (compared to the Hadley) result in higher price decreases. Large price decreases compared to the moderate production increases can be explained by the relatively low demand and supply elasticities for agricultural products.

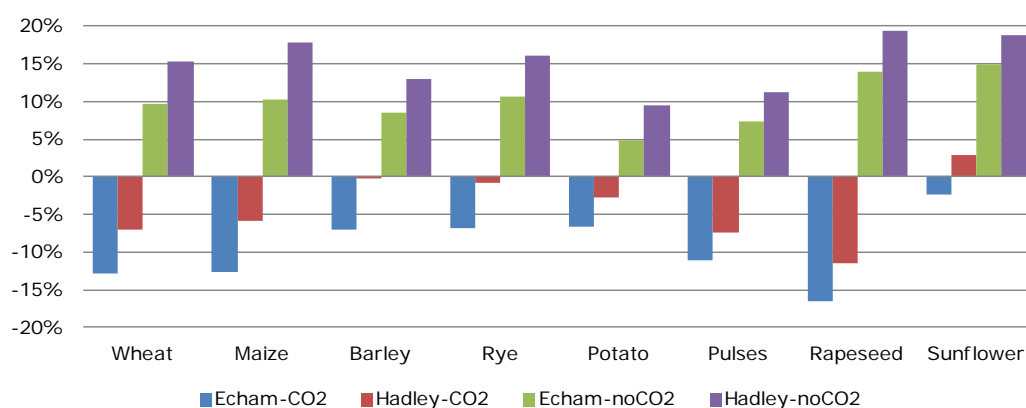


Figure 5. Effects on global producer prices (% change from baseline)

With carbon fertilization, the heterogeneous yield change among regions in the world influences directly their relative productivity and the competitive advantage on the international scene. As can be seen in figure 6, agricultural production in the EU is expected to decrease despite the positive yield developments, due to less competitive prices and a worsening of the trade balance. This shows that the economic impact is able to reverse the outcome of the yield change.

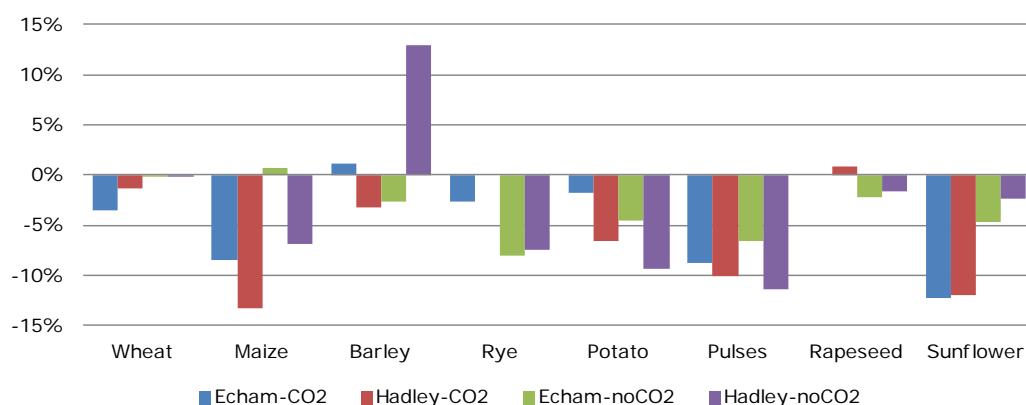


Figure 6. Effects on EU production (% change from baseline)

3.3. Uneven effects across European regions

Within the European Union, strong regional divergences in production effects exist (Figure 7). Overall, production changes mirror changes in yield and relative productivity. However, price changes will induce adjustments both at the intensive margin and at the extensive margin.

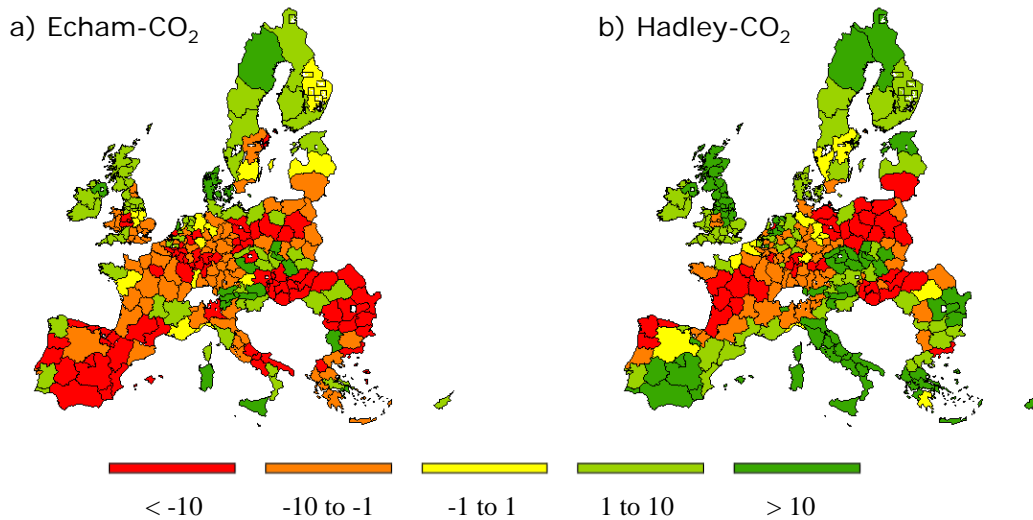


Figure 7. Regional cereal production (% change from baseline)

Extensive margin adjustments are illustrated in Figure 8, showing that climate change will induce redistribution of cereal production.

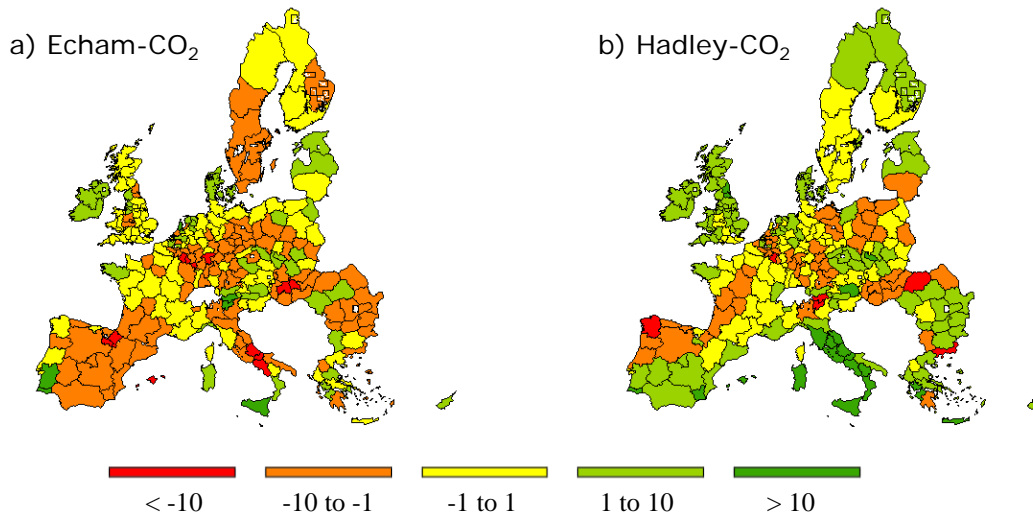


Figure 8. Regional cereal area (% change from baseline)

Overall, EU agricultural income drops by 3.4% in the Echam realization and increases by 0.5% in the Hadley. Regional effects on agricultural income are shown in Figure 9. In the Echam realization, crop price decreases more than offsets productivity increases, leading to moderate income decreases in most EU regions.

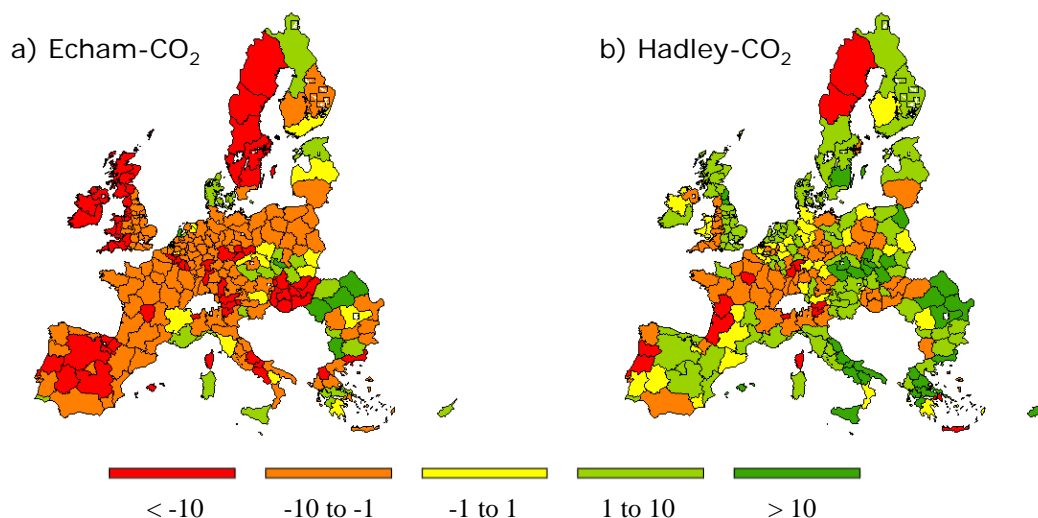


Figure 9. Regional agricultural income (% change from baseline)

4. Conclusions

Projections for world food production and prices play a crucial role to evaluate and tackle future food security challenges. Understanding how these projections will be affected by climate change is the main objective of this study. In this study, we use a bio-economic approach to jointly assess biophysical and socio-economic effects of climate change on agriculture, providing both a global analysis and a regionalised evaluation within the EU. To account for uncertainty, we analyse the IPCC emission scenario A1B for the 2030 horizon under several simulation scenarios that differ in (1) the climate projection, HadleyCM3 realization (warm) or ECHAM5 realization (mild); and (2) the influence of CO₂ effects.

Biophysical simulations show that climate change impacts on crop yields vary widely across EU regions and crops. Comparing simulation scenarios, we observe that the carbon fertilization effect can strongly influence the direction of effects both for EU and non-EU regions. Therefore, more research on the exact yield impact on regional level of CO₂ fertilization is necessary. Economic simulations demonstrate that crop prices will react to yield changes, attenuating the effects of climate change at the global level, but having divergent effects across regions depending on the magnitude and direction of yield changes and their impact on productivity.

Results of this study indicate that agrifood market projections to 2030 are very sensitive to change in crop yields and, therefore, to climate change and assumptions made on the carbon fertilization effect. They show as well that market forces and changes in competitive advantages can reverse the effects of yield changes.

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